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Center for Advanced Computation Document No. 32

Center for Advanced Computation

SEMI-ANNUAL TECHNICAL REPORT

July 12, 1971 - March 31, 1972

Advanced Research Projects Agency

Contract No.
DAHC04-72-C-0001

Center for Advanced Computation
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

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REPORT SUMMARY

This document reports progress on ARPA contract DAHC04-72-C-0001 entitled "ILLIAC IV Applications Research at the Center for Advanced Computation, University of Illinois at Urbana-Champaign." The principal objective of this program is the development and testing of numerical techniques and software systems for use of ILLIAC IV over the ARPA Network. This is being accomplished through activities in the following areas:

1. Development of numerical techniques suitable for parallel processing in the following areas:
   a. Computational Methods in Linear Algebra.
   b. Linear Programming.
   c. Ordinary and Partial Differential Equations.
   d. Time Series Analysis.
   e. Quadratic Assignment Code.
   f. Graphics.
2. Development of ARPA Network facilities and associated systems consisting of:
   a. Project to interface the B6700 to the ARPA Network.
   b. ARPA Network Terminal System (ANTS).
   c. Center Graphics Support.
   d. Network Graphics Effort.
3. Development of a large scale applications system, dealing with input-output economic modeling, utilizing ILLIAC IV algorithms and several ARPA Network facilities.
4. ILLIAC IV Language Development.
5. ILLIAC IV Information Retrieval and Statistical System (IRSS).
6. ILLIAC IV Image Processing.

In addition, education of segments of the ILLIAC IV user community was accomplished through seminars, classes, and the development and dissemination of tutorial materials.

1. ALGORITHM DEVELOPMENT GROUP

1.1 Introduction

The main objective of this group is the development of numerical techniques that are most suitable for parallel machines, namely the ILLIAC IV. The research program can be divided into the following areas:

(a) Computational Methods in Linear Algebra
(b) Linear Programming
(c) Ordinary and Partial Differential Equations
(d) Time Series Analysis
(e) Quadratic Assignment Code
(f) Graphics

In developing any parallel algorithm, we first implement the existing serial algorithm on the B6700 (in Algol). Once the programmer is familiar with the computational characteristics of that routine, the parallel algorithm is then designed. In many instances, the parallal algorithm is substantially different from the serial one, in which case the parallel routine is written on the B6700 in Algol to check its validity, accuracy, rate of convergence, etc. The last step is then writing Glypnir or ASK code, and finally debugging it on the B6700 simulator (SSK). Due to the slow speed of the simulator, many codes cannot be debugged completely. Some time consuming codes have been coded in Glyplit (Glypnir to PL/1 translator developed at RAND) for fast checking of their logic only.

The group has adopted a verification process of the algorithm in which each member tries to use and test algorithms developed by other members. This leads to the discovery of well-hidden bugs and helps in pointing out areas of needed standardization and documentation, as well as improving the codes being reviewed. A listing of the Center's Subroutine library is now available, [1], which identifies available debugged algorithms, describes their function, the language in which they are written, and the author.

1.2 Computational Methods in Linear Algebra

1.2.1 Solution of Systems of Linear Equations

(a) An ASK program was developed to solve systems of linear equations $Ax = b$ for many right hand sides, where A is a banded positive definite symmetric matrix. Work has been completed on the algorithm to handle matrices of band-width < 64, and the algorithm for bandwidth < 127

is currently in the debugging state.

Enroute to the ASK algorithm, two routines in Algol were extracted from Wilkinson and Reinsch's Linear Algebra, [2], for incorporation in the group's subroutine library:

(i) a routine which decomposes the banded matrix, and

(ii) a routine which given the decomposition, proceeds to determine the solution vectors for many right hand sides.

Documentation on the Algol program is completed, and the ASK programs will be documented upon their completion.

(b) A program for the decomposition of a matrix into the product of lower and upper triangular matrices for the solution of linear equations or matrix inversion, [2], has been completed in ASK for non-core contained matrices (order = 1000). The program has been debugged as far as possible but the slow speed of the simulator and lack of satisfactory input/output routines have precluded further checking until the machine becomes available. A document is forthcoming. A Glypnir program for solving complex systems of linear equations, order 64, by the LU decomposition has also been completed, [2,3,4].

(c) An ASK program of the Householder triangularization, [3], of a matrix and back-substition for solving core-contained systems of linear equations (order = 300), is now in the final stage of debugging on the SSK simulator. The routine consists of seven external subroutines and a master program, all of which are checked out independently. The task presently in progress involves combining individual subroutines, several at a time, for checking on SSK without exceeding its capabilities.

Householder's Modification method for matrix inversion has also been coded and debugged in ASK but only for matrices of order 64 or less since the number of operations is higher than that of the LU decomposition or Householder triangularization. The method seems to be suitable for sparse matrices. A document describing both Householder's triangularization and the Modification methods is forthcoming.

(d) The conjugate gradient method for solving linear equations $Ax = b$, [2], has been coded in Algol to gain experience in the technique. Glypnir coding is proceeding but has been somewhat hampered by lack of facilities in the language, namely the inability to call the

subroutines as parameters. This algorithm requires as an input a routine to compute Ay and $A^t y$ for a given y rather than an explicit representation of the matrix A. This should prove to be very fast in cases where A is sparse and of regular structure.

1.2.2 The Algebraic Eigenvalue Problem

(a) Two ASK programs for parallel Jacobi and Jacobi-like algorithms, for real symmetric and real nonsymmetric matrices of order 64 or less, have been completed, and a document has been published [5]. An improved parallel Jacobi algorithm has been developed [6], and an ASK program has been completed and documented [7]. Several experimental Algol and Glyplit programs have been written to explore the possibility of improving the convergence of already published Jacobi-like algorithm [5,6].

(b) The QR algorithm for finding the eigenvalues of symmetric tridiagonal matrices has been coded in Glypnir.

The QL algorithm [2] for finding the eigenvalues and eigenvectors of symmetric tridiagonal matrices has been coded and tested in Algol and being programmed in Glypnir. A generalization of the bisection method together with inverse iteration have been programmed and tested in Algol. Both routines are being programmed in Glypnir to produce a parallel algorithm, [8], with higher efficiency than the inherently serial QL algorithm.

(c) The conjugate gradient algorithm for finding the largest and smallest eigenvalues and the corresponding eigenvectors of the generalized eigenvalue problem $Ax = Bx$ where A and B are symmetric positive definite matrices, [9], has been coded and tested in Algol and will be coded in Glypnir with high efficiency of parallelism. As mentioned earlier, Az and Bz can be generated implicitly for any vector z, when A and B structured, sparse matrices (which is the case in most practical applications).

(d) The accelerated power method for finding the largest eigenvalue and the corresponding eigenvector has been coded and tested in Algol and Glyplit. This method, mentioned by Wilkinson [3] (ad hoc shift of origin) for man-machine interaction, was modified so that it would not require interaction unsuited for the ILLIAC IV. A variation of the above power method now being tested, where the L_2 norm is used

instead of the L_∞ norm, is just as fast on the ILLIAC IV and more predictable, hence more suited to unmanned operations.

(e) The QR algorithm, with origin shift for the solution of eigenvalue problems, [2], has been coded in ASK for non core-contained matrices and is being debugged. The reduction to upper Hessenberg form using Householder's transformations, [2], of non-core-contained matrices is almost totally debugged.

An ASK program for reducing core-contained real matrices to the upper-Hessenberg form using elementary stabilized transformation [2] is completed. Two documents containing ASK codes for the QR algorithm and Householder reduction to upper-Hessenberg form for matrices of order 64 or less are available [10,11].

(f) An algorithm for establishing error bounds on the complete eigensystem of core-contained (order = 90) diagonable matrices [12] has been coded in ASK and is in the debugging stage. This should reveal some of the favorable aspects of parallel computation.

(g) A numerical method for obtaining the eigenvector solution of the non-linear matrix Riccati equation has been programmed and fully tested in Glypnir, and a complete document is available [3].

(h) Work has begun only recently on the development of an eigenvalue algorithm for obtaining all eigenvalues and vectors of sparse matrices. As a first step such an algorithm was developed for matrices whose Gerschgorin disks are all isolated. The resulting parallel algorithm has for its basis the work of Varga and his associates on the best isolated Gerschgorin disks [13,16]. The Algol program has been extensively tested; results obtained compare favorably in accuracy with the QR algorithm. Work continues on the general case where the Gerschgorin disks cannot be isolated by diagonal similarity transformations.

1.3 Linear Programming

(a) The goal of the initial LP codes is a solution capacity of 16,000 row problems with a potential for expansion to 64,000 row problems. Codes initially available will be PRIMAL, a modification of the revised simplex method utilizing a product form of the inverse, and INVERT, a reinversion program based on the Hellerman-Rarick preassigned pivot procedures. Supporting these computational portions are the data massaging SETUP and SETDOWN codes which create initial files and produce

result-files, respectively. The LOADER, a B6500 program, accepts the data in MPS/360 form and after sorting passes this data to the ILLIAC IV disk. SETUP then utilizes the ILLIAC to convert the values to suitable word formats, classify columns and rows, scale these columns and rows, and emit those files necessary for PRIMAL and INVERT. SETDOWN picks up at the termination of the PRIMAL-INVERT symbiosis and rescales and edits the output, still using ILLIAC. An UNLOADER will eventually be written to replace the internal (numeric) with the original external (alphanumeric) labels and to prepare printer output.

The Linear Programming group, presently staffed by fewer then two full-time staff members, progressed steadily through INVERT coding. INVERT has been divided into three sections:

(i) the creation of an implicit in-core matrix representing the basis vectors,

(ii) the identification of the pivot sequence for the new Product Form of the Inverse (PFI),

(iii) the creation of the ETA files representing the PFI.

The first two sections have been coded and simulated; while their lack of parallelism makes them less than satisfactory, they are the best algorithms identified so far. The third section appears to make very good use of the parallelism of the machine and should be simulated by the end of the present quarter.

PRIMAL has been coded and debugged as fas as the simulator could allow. The major revision being considered is the inclusion of debugging and diagnostic routines. A lack of response to our letters requesting information from NASA/AMES Institute for Advanced Computation (ascribed to a shortage of personnel at IAC) has postponed a rewrite of our I/O utilities and the development of these diagnostic routines. Information obtained at the March 1972 user's conference at Monterey suggests that ILLIAC IV will not begin to support LP's I/O requirements for some time.

The SETUP routines are nearly completed and, with the current resolution of the last section of INVERT's flowcharts, should be quickly disposed of. Documentation of all coded routines are available and will be combined into one document describing the whole system once unresolved

issues about ILLIAC IV are settled.

(b) Preliminary investigation of methods to reduce storage and computation time for large Linear Programming problems have begun. This would be achieved by performing all matrix operations (e.g., calculating Ax and $A^T y$ given x,y) implicitly without ever generating and storing the matrix A. Used with a matrix generator, significant savings may be obtained.

1.4 Ordinary and Partial Differential Equations

(a) A preliminary study for an ordinary differential equations solver for ILLIAC IV has been completed and a document is available [17].

(b) Two Glypnir codes have been completed for the alternating direction implicit iterative technique (ADI, 64 rows), and the block-Jacobi method (128 rows) for the solution of second-order elliptic partial differential equations. A document describing the block-Jacobi method on the ILLIAC IV is forthcoming.

(c) A Glyplit program has been written which performs simultaneous fast Fourier transforms of real functions in all enabled PE's. At present, the program is core-contained. This program may be useful when solving partial differential equations by means of a change of variables that can be carried out by the fast Fourier transform [18].

(d) A Glypnir program implementing J. Son's (Department of Chemical Engineering, University of Illinois at Urbana-Champaign) solution to the problem of flow around a cylinder has been coded and debugged on the simulator. It is estimated that a 50% reduction in run time can be achieved by coding in ASK the section which solves Poisson's equation iteratively.

Direct methods for solving Poisson's equation appear to offer additional reductions in run time. Hockney's direct method has been implemented in serial form in Algol. This algorithm was compared to a serial SOR and found to be about twice as fast for those cores tested.

A direct algorithm for solving Poisson's equation in an irregular domain using a Hockney type formulation is being developed. A serial iterative algorithm has already been developed in Algol for these irregular domains.

Various boundary conditions are also being tested in an

attempt to better model the physics of this fluid flow problem.

(e) A computational technique for high subsonic compressible inviscid flow past a circular cylinder has been implemented serially on the CDC 1604 computer; a Glyplit code will be written soon. Boundary conditions are chosen for maximum utilization of the processing elements. Procedures for varying grid sizes without changing the PE instruction stream have been developed. The calculated results compare well with those obtained by Holt and Masson [18] by the method of integral relations. A document has also been completed [19] in which the relevant and practical criteria required for the numerical calculation of different types of gas dynamic flow fields are discussed.

(f) Glypnir programs have been written to solve a set of differential equations used in atmospheric dynamics to describe fluid convective motion induced by the buoyancy force and heat transfer associated with the motion. Time comparisons have been made between these programs and CDC 6400 FORTRAN programs for a 64 x 17 mesh. The ratio is about 1:110 when successive overrelaxation method is used in solving Poisson's equation. To improve this ratio, the kernel of this program was programmed in ASK. The ratio is thereby improved to 1:220 as the result of storing constants in ADB's, making more efficient address calculations, and increasing the amount of overlap between PE and PEM. Detailed analysis of the kernel of Glypnir and partially ASK-coded programs have been performed.

In solving Poisson's equation, the efficiencies of three popular iterative methods (SOR, SLOR and ADI) have been compared on ILLIAC IV. The storage schemes and methods of implementation which maximize the efficiency of these algorithms on ILLIAC IV have been investigated. The implementation of the direct method in solving Poisson's equations on rectangular regions with various boundary conditions is under way. Detailed reports of this work will be available next quarter. These studies on the efficiency of ILLIAC IV in atmospheric dynamics calculations are jointly supported by ARPA and the National Science Foundation.

(g) Algorithms for the "identification" of non-linear differential equations have been developed. Such algorithms will allow determination of certain sets of differential equations that satisfy a set of

data provided as input. These routines have been implemented on the B6700 in Algol; however, many features are suitable for parallel machines. A document will soon be published. We believe that the developed package will be of interest to many of the ARPA community who are involved in mathematical model building. If the response is favorable, work will proceed on implementing the package on ILLIAC IV. This is the first of three studies begun at the Center for mathematical model building. The other two studies are stochastic model building and identification of linear and periodic dynamic systems which are described in Section 1.5.

1.5 Time-Series Analysis

(a) A Fast Fourier Transform (FFT) subroutine has been written in ASK, and fully debugged and tested. Timing simulation results have shown that this program will perform Fourier transforms on ILLIAC IV with good efficiency. A descriptive document and a user's manual are available [21].

(b) Glypnir codes for a one-dimensional FFT, autocorrelation, and computation of the impulse response of a band-pass filter are fully debugged and tested. A document is forthcoming.

(c) A document has been completed [22] describing a B6700 package developed to determine the stochastic model used to describe observed data (which is in the form of time series), determine the order of the model, and estimate the parameters using a maximum likelihood. The feasibility of using parallel computations in this study, especially for the estimation algorithm, is being considered.

(d) Algorithms have been developed for the identification of linear time-invariant and periodic (period is not known a priori) dynamic systems using only the observed data (no control inputs). A B6700 Algol package is now being completed. The obtained results are very satisfactory. Many parts of the developed algorithms are suitable for a parallel computer, especially since the identification of a periodic system is reduced to the identification of many (64) linear system. Again, we believe this study to be valuable for researchers involved in mathematical model building (Economics, Biology, Engineering, etc.).

1.6 QUASCO: An ILLIAC IV Quadratic Assignment Code

As part of the ILLIAC IV algorithm development effort (and

in support of CAC hardware design research) a modest effort is underway to formulate and code efficient parallel procedures for treating the quadratic assignment problem. The results of these investigations to date, though incomplete, seem encouraging.

The quadratic assignment problem requires a one-to-one matching of the elements of two sets such that a quadratic objective function is optimized. For example, in the area of computer hardware design it is often desirable to assign discreet positions on a wiring board to some number of interconnected components in such a manner that the total length of connections between components is minimal. Other applications of the model relate to optimal industrial plant layout, hospital design, office space allocation, urban planning, etc.

A possible notation for the problem (in simplified form) is:

$$\min_{\rho} \sum_{i=1}^{n} \sum_{j=1}^{n} c_{\rho(i),\, \rho(j)} \cdot d_{i,j}$$

where:

$[C_{\rho(i),\rho(j)}]$ = an n x n matrix expressing the cost per unit distance between any two elements of the first set (components, plant functions, departments, offices, activities, etc.).

$[D_{i,j}]$ = an n x n matrix expressing the effective distance between any two elements of the second set (positions on a printed circuit board, spaces within a plant, hospital or office tower, city blocks, etc.).

ρ = a permutation of indices of the elements of the first set corresponding to a one-to-one matching to the elements of the second set.

While integer programming formulations of the problem are possible, the effect of the resulting quadratic objective function and integer constraints is always to create non-convexities in the solution space and hence numerous locally-optimal solutions. It may indeed be impossible to compute global optima for large quadratic assignment problems, even on ILLIAC IV.

Thus, our attack has focused more on the development of parallel procedures for approximating optimal solutions. Since these methods

employ hill-climbing programming strategies, the solutions depend to some extend on starting points (initial feasible assignments derived by chance or design). Given such algorithms and an appropriate sampling strategy, however, the speed at which ILLIAC IV will be able to generate and rank alternative approximations will afford more confidence in the calculation and employment of best approximations to the optimal solution.

An existing quadratic assignment code developed by a staff member was re-written in Algol for the B6700 in order to realize efficient computer usage and inexpensive costs. Extensive improvements were made to the algorithm; however, it still remains in a state of dynamic change. Test results thus far indicate that QUASCO has achieved better results than other known algorithms. Work will proceed on an ILLIAC IV routine when this heuristic algorithm becomes better formulated.

A report is forthcoming in which are presented several ideas on the quadratic assignment problems and the approximation of one matrix by another of lower rank.

1.7 Graphics Algorithm Development for ILLIAC IV

1.7.1 Surface Presentation of a Function F(X,Y)

A basic ASK routine was completed for the perspective presentation of a graphical image of a surface represented by the function of two variables, X and Y. The design and implementation of this algorithm, however, is based on the still not rigorously defined input/output and disk access aspects of the ILLIAC IV operating system. Further work in sending the graphics data stream of this algorithm from ILLIAC IV into its control system has been suspended pending the suitable definition of the control system by Ames. As soon as the new I/O system to ILLIAC IV is defined, and the programming conventions established, this algorithm will be remolded to fit the new concepts.

1.7.2 Contour Plotting Algorithm for ILLIAC IV

A new contour plotting algorithm for the M x N array case, using real variables, was developed using SSK. The new implementation is a single program specifically designed to take advantage of parallel processing, both in the calculation of the contour data and in the resulting production of graphical images.

The current version of the algorithm assumes the case of an M x N array of data which is entirely core contained. Further work on

this algorithm development was halted pending complete definition of the input/output system by Ames.

When work resumes, the case of an M x N array not core contained (partially or wholly on disk) will be completed and the input/output portions of the algorithm adapted to the new conventions for the Ames system.

1.8 Miscellaneous

(a) Two algorithms for finding the roots of polynomials with real coefficients have been programmed in Algol-Root-Squaring and an algorithm for finding the real roots using the Sturm sequence property. A parallel algorithm is now being designed to find the real roots of real polynomials using the Sturm sequence property.

(b) A short experiment in 8-fold precision on modular arithmetic was carried out using eight prime numbers furnished by the DeKalb Foundation for Number Theory.

(c) The block triangular decomposition of large matrices for eigenvalue problems by means of the transformation of $B \rightarrow PBP^{-1}$, where P is a permutation matrix, has been considered. The method used finds the transitive closure of the digraph G associated with B.

An Algol program was written and tested to put a 48 x 48 matrix in block triangular form, making use of the B6700's ability to logically find the "and" of two 48-bit words in one instruction. Then the program was extended to n x n matrices using the same method. The program works, and is now being documented.

The central part of the above program is the calculation of the transitive closure of a digraph. An ASK code to do this for a 64 x 64 matrix on ILLIAC IV using Warshall's algorithm [22] has been written; it will be extended to a 64n x 64n matrix. The algorithm is extremely fast on ILLIAC IV compared to conventional machines.

(d) Other Algol routines added to the group's library were:

- Householder's reduction of a symmetric matrix to tridiagonal form.
- Newton's method to obtain a root of $f(x) = 0$.
- Wegstein's secant method to obtain a root of $x = f(x)$.

The above secant method was programmed in ASK to run in a serial mode on ILLIAC IV.

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2. COMPUTER SYSTEMS AND SERVICES GROUP

2.1 Introduction

The Computer Systems and Services group is responsible for developing local basic computer systems and services to serve the needs of the Center staff and user community. There are four project areas to be reported on at this time:

(a) Project to Interface the B6700 to the ARPA Network

(b) ARPA Network Terminal System (ANTS)

(c) Center Graphics Support

(d) Network Graphics Effort

2.2 Project to Interface B6700 to the ARPA Network

During 1971, Burroughs developed two full-capability interfaces for interfacing a Burroughs B6700 computer system to the ARPA via an Interface Message Processor. Two interfaces were completely constructed and one of the interfaces was completely debugged.

Software drivers for these interfaces were completed and debugged during the Fall of 1971. This included a series of patches for the MCP, as well as the device driver intrinsics for the MCP. In addition, a full-size Network control program was 90% coded and partially debugged.

When it was decided that Ames would not interface their B6700 to the Network, and when it appeared that the University of California at San Diego would write their own network control program, all effort was stopped on the project. The hardware portion of the project was completed and the NCP has been left at the 50% completion level.

It is anticipated that, in the near future, UCSD will interface their system directly to the Network and will use one of the hardware interfaces. They will also incorporate our MCP patches and intrinsics into their system. The Center will aid UCSD in developing their NCP, but will discontinue an independent effort in this area.

2.3 ARPA Network Activities

2.3.1 ARPA Network Terminal System (ANTS) Development

At the beginning of the reporting period, development of the ARPA Network Terminal System (ANTS) was seriously affected by failure of

the B6700 performance to meet expectations. Progress was slow, erratic, but forward. Two full-time staff members have participated in the development of ANTS - one devoted to developing the high-level language compiler PEESPOL in which the system is written, while the other was responsible for the ANTS implementation.

On September 1, 1971, ANTS achieved Network operational status at the level of terminal access to the Network. Since September 1, efforts have been directed to consolidating the design and implementation of the full basic system in order to facilitate the system functions described below.

As of March 1, the basic system modules have been completed and the overall system structure set. Future efforts will be directed at implementing all applicable Network protocol operations, such as the low-level graphics protocol, data and file transfer protocols, extended terminal access protocols, including all required device drivers for peripheral devices, DECtapes, magnetic tapes, Gould printer, card reader, disk and graphics displays. As of April 1, ANTS provides remote job entry access to the UCLA IBM 360/91.

2.3.2 ARPA Network Usage

With operational status of ANTS on September 1, 1971, the Center acquired minimal capability for connecting to the Network. It was quickly established, however, that the Network was in an early stage and service capabilities were undeveloped. Since September, experience on the Network has been primarily limited to attempts to use the BB&N service site in Cambridge and the Network Information Center at Stanford Research Institute.

More Network sites have become available during the period. With the recent addition of remote job entry capability to UCLA, Center usage of the Network will rise through the use of the GLYPLIT translator on the 360/91 and through the use of the number-crunching capabilities for running large codes. Additionally, the Center is aiding the University of California at San Diego in connecting their Burroughs B6700 to the Network by early June. This will enable us to transfer work now being done on our B6700 to San Diego via the Network. The Center's B6700 lease arrangement terminates on June 30, 1972.

2.3.3 Further Installations of ANTS Systems on the Network

During the Fall of 1971, the National Bureau of Standards (NBS) Information Processing Techniques group acquired and installed an ANTS system. Due to the hardware problems, both in the Network TIP and the NBS PDP-11 system, this site has not yet reached operational status. It is expected in the next quarter that installation of the site will be complete as well as installation of the proper drivers to handle the DCT 2000 integrated remote job entry terminal which NBS already has acquired and through which they intend to access the 360/91 at UCLA. NBS intends to use their version of ANTS to perform experiments and gather data on system performance, on the use of terminals to various ARPA Network sites, and on activities between systems on the Network. They will be modifying their operating version of ANTS through the PEESPOL compiler on the UCSD B6700 to provide them with necessary input/output and data collection capabilities to facilitate these experiments.

Additionally, it is expected that two more installations of the ANTS systems will be made at Ft. Belvoir, Va. and Aberdeen, Md., both sites of the Army Material Command (AMC). Ft. Belvoir will use ANTS to interface remote job entry terminals to the Network and to connect a CDC 6600 to the Network. Aberdeen will obtain remote job entry access to the Network through ANTS to permit their AMC people to use the Ft. Belvoir CDC 6600 and other Network resources.

2.4 Graphics Support for Center Projects on the B6700

The development of a graphics package for the B6700 for use by the Center personnel was supported for two reasons: 1) there were a number of graphics devices on the PDP-11 which we wished to make available to people using the B6700; and 2) it was expected that this experience would aid in development of graphics packages for ILLIAC IV and any future Network systems in which we participated.

The connection of the PDP-11 to the B6700 was undertaken by writing a special operating system for the PDP-11 which attached it, via an 1800-baud telephone line, to the B6700 and made the PDP-11 peripherals look like terminals operating from the B6700 Datacom processor.

Further efforts were then directed at providing a basic graphics package with all rudimentary graphics operations such as line drawing, point drawing, lettering and scan graphics for faster scan

conversion to the Gould electrostatic printer.

With the completion of this package in the Fall of 1971, efforts were then extended to the development of basic programming modules for plotting axes, scaling data, plotting lines from arrays, etc. In addition, a driving package was developed which allows one to interactively drive these programs to produce graphical imagery.

The decision was made to cease further development of B6700 graphics in January and to concentrate efforts on developing capabilities to the Network and in the use of other Network host sites for Center personnel. Prior to this time, much experience was gained on the B6700 and some initial design on a generalized graphics data structure was completed and tested.

2.5 Network Graphics Efforts

2.5.1 Network Graphics Protocol

Several staff members are participating in the Network graphics group in an attempt to establish protocols for the transmission of graphical information across the Network. During the first quarter of 1971, agreement was reached on first level graphics protocol whereby graphical images were sent from the serving site to the using site in a very basic interpretive format allowing conversion into device specific format to such devices as the ARDS. Tektronix, Computek and IMLAC graphics display consoles. Future efforts will expand this interpretive language to provide for subroutining and dynamic interpretive display of subpictures.

2.5.2 Laboratory for Atmospheric Research (LAR) Support

With the advent of remote job entry to the UCLA 360/91, efforts are being directed at developing the necessary graphical routines and packages on the model 91 so that work there by Center and LAR personnel can be retransmitted back to the Center's graphical facilities attached to the PDP-11, i.e., the Computek display scope and the Gould electrostatic graphics printer. This effort will produce systems necessary for activities in the University's Atmospheric Research Laboratory under the direction of Professor Ogura. In addition to direct display from UCLA, a third party access through the Rand Tenex system will be performed whereby researchers interactively select their graphics displays and formats after their problem has been run and large output files produced.

3. ECONOMIC RESEARCH GROUP

3.1 Introduction

During this period, the Economic Research Group has been engaged in an effort to develop a general manpower, economic and educational forecasting model which would be broadly useful to a large group of users in many agencies at the national, state and local level, to private businesses engaged in planning, and to scholars and students of economic, manpower and educational planning.

The Center's econometric research for the models used has been supported from several sources, including the U.S. Department of Labor, Manpower Administration and Offices of Policy Development, the University of Illinois, and ARPA. Further development of the econometric models will be supported by other agencies and foundations. ARPA support will be used to develop the user interface, ILLIAC IV computational system, and for development of a large applications system which is distributed over the Network.

The STEP I model, which is almost complete, forms the first version of this model. STEP II, which has begun, is a more complex version of STEP I entailing more sophisticated economic modelling and making much greater demands on computational systems. STEP I is implemented on conventional sequential computers. STEP II will require the computational capacity of ILLIAC IV because of the large computational capacity needed for matrix operations. The entire system by which remote users will access the model library data files, and computer utilities needed for economic, manpower and educational planning is termed MEASURE (Manpower and Economic Analysis System for Use in Research and Evaluation). MEASURE is to be developed in a form which is accessible to economists, planners, budget experts and others who are not trained in econometrics and computer science. Properly implemented, MEASURE can provide very large economies to users, and, ultimately, to the various governments whose needs create the demand for planning and forecasting. Most important, MEASURE permits the planner a much higher degree of freedom in developing his plans since a much larger proportion of the analyst's time is devoted to specifying and evaluating his projections rather than in the mechanics of data collection, model specification, and data processing.

It is by providing the econometric skeleton, highly user-oriented computer interface, extensive data files, and efficient utilization of Network computers ranging from the PDP-10 through the IBM 360/91 to ILLIAC IV and the low-cost communications capability of the ARPA Network that MEASURE will substantially reduce the costs of any particular forecast and enlarge the community of planners and forecasters who can use sophisticated forecasting models.

Although ARPA sponsorship will be limited to system development work related to ILLIAC IV, distributed system experimentation on the Network and user-interface design, we describe STEP I and STEP II in some detail to provide the proper context for these developments.

3.2 STEP I

The STEP I model consists of sub-models of Population, Labor Force, Enrollment, Industrial Demand, Demand for Employment by Industry, Occupational Demand, and Occupational Supply. The model will be implemented for the United States as a whole and for the State of Illinois.

The sub-models are related as follows: the Population model provides population projections by single years of age, color and sex for any future year. The Labor Force model uses the population projections to produce labor force projections. The School Enrollment model uses the population projections to produce school enrollment by grade for any year in the future. The Occupational Supply model uses the results of the Population, Labor Force and Enrollment models and the Occupational Mobility model to generate occupational supply projections for any future year. The Alternative Budget model generates alternative patterns of final demand by industry for alternative assumptions of the pattern of economic and social development of the United States. The Industrial Demand model generates the pattern of demand for output of the various industries for the alternative expenditure assumptions. The Employment Demand model generates the patterns of employment by industry associated with the alternative industry demand patterns. The Occupational Demand model generates the alternative patterns of occupational demand associated with the alternative expenditure assumptions.

The state model is based on the fundamental assumption that a state's share of national industry employment can be accurately projected.

STEP I, while a highly simplified version of reality, repre-

sents a considerable extension of forecasting capability for the user. It is the most comprehensive and general model of the employment process which has yet been developed. There is little question that use of STEP I in the preparation of state, local and national projections would represent a considerable improvement over existing methods.

The modular design of the model and its high tolerance for modified assumptions permit STEP I to be easily adapted to a large number of special purposes. It is structured in a fashion that permits the user a large degree of latitide in introducing his own assumptions, in extending the model to encompass the desired detail, and to add on special elements. At the same time, the model is itself complete, and can be used for several specific applications with no modification or user input specifications (except to identify his particular output choice).

The initial demand forecasts prepared using the demand model for the United States and for Illinois and the description of the use of the STEP I model will be published as CAC technical reports in the next quarter.

One of the critical problems in the development of reliable forecasting models is the sensitivity of the model to errors of specification. Very little work has been done on the sensitivity of input-output models to misspecification because of the large costs of inverting dense matrices of large order. The availability of ILLIAC IV and its accessibility over the network will permit significant experimentation on the sensitivity of estimates to misspecification of various components of the model. During 1973 the Economic Research Group will carry out extensive sensitivity tests of STEP I and other large input-output matrices in order to identify components of the model which are most critical to model forecasts.

3.3 STEP II

STEP II represents a considerable extension of STEP I in the direction of increasing its realism, and presumably its accuracy in forecasting and its utility as a research tool. STEP I relies on the projection of critical coefficients by the judgement of the system developers. The projected activity-industry coefficients, input-output coefficients, employment coefficients, occupational coefficients, birth

rates, mortality rates, labor force participation rates, and occupational mobility coefficients are based on the judgement in the development of the system. STEP II envisages forecasting essential parameters of the model as the result of a formal, continuing and organized system of technological forecasting. It is not contemplated that the technological forecasting necessary to develop best estimates of the parameters will be conducted in-house at the Center, but that the MEASURE system will provide a vehicle by which comprehensive, consistent and complete technological forecasting might be carried out using STEP II as a basic model or context for the forecasting. Because STEP II maintains the basic extended modular design of STEP I, it will be possible for the technological forecaster to develop conditional forecasts for the particular parameters he is forecasting without requiring all other forecasters to meet and agree on basic underlying assumptions. For instance, the demographic forecaster who wishes to build economic influences into his population parameters can specify the economic preconditions for various sets of his parameter estimates.

The Center plans, however, to identify technological forecasting efforts now underway and to introduce these groups to the MEASURE system. It is expected that the availability, comprehensiveness and economy of MEASURE will appeal to the forecasters and induce them to join the MEASURE users group.

In addition to technological forecasting, STEP II will also differ from STEP I in having a system of dynamic adjustment to labor shortages and surpluses. STEP I simply generates forecasts of occupational supply and demand, but STEP II will include processes to predict the labor market adjustments which result from excess supply or excess demand.

Moreover, STEP II will integrate the input-output models of flow in the economy in the forecast year with an annual econometric forecasting model. STEP I is based on the distribution of an aggregate economic output arrived at through projection of aggregate economic growth, but an annual econometric model will restrict the available econometric output to particular macro-economic aggregates, such as exports, consumption and investment. Specification of alternative patterns of expenditure for STEP I simply requires the specification of alternative

levels, but STEP II will require the specification of alternative developmental paths. In STEP I the question is, "What will happen if a specified pattern of expenditures occurs in 1980?" In STEP II the question is, "What will happen if this course of economic development occurs between now and 1980?"

The complexity of STEP II and its requirements for large-scale interaction between experts in all parts of the country should provide a major experiment in the facilitating of research by the use of the diverse computational resources and communications capacity of the ARPA Network.

3.4 MEASURE

The MEASURE system is the communications-software-hardware system which will make STEP I, STEP II and other econometric models and data available to remote users. The principal components of MEASURE are:

(a) The MEASURE operating system on the host computer.

(b) The ARPA Network.

(c) The computational packages distributed over several Network computers including ILLIAC IV.

(d) The Model Library.

(e) The Data Library.

It is expected that a MEASURE user will access the MEASURE host through the Network to develop and edit his particular model (which will be based on one of the models in the Model Library that will include STEP I and STEP II). Using his own data and that available from the Data Library the user will specify his model. When he completes editing and instructs the system to perform the indicated calculations, the MEASURE system will use a process allocation algorithm to assign the problem to the hose computer, or a larger machine (such as the 360/91 or ILLIAC IV). Output from the computation may be stored for analysis at the MEASURE host computer. The development of the process-allocation algorithm and the necessary computational packages for the host, 360/91, and ILLIAC IV are principal future tasks planned under ARPA support. It is expected that the process allocation algorithm will be generally useful in optimizing use of network resources.

Successful functioning of the MEASURE system obviously depends on the availability of usable models, the data library, and a community

of users. The STEP I system provides a considerable advance in the state of the forecasting art but as long as its use is limited to the local community, occasional visitors, and those remote users able to pay the substantial costs of normal long-distance telephone connection it will not be fully utilized. There is little benefit in developing the software for such complex systems unless the essential components are likely to become widely available and unless there is effective demand for the system. At the same time, it is difficult to measure effective demand for such a system until it is specified, with a firm date for availability and narrowly defined user costs.

In 1972-73 the Center will be engaged in experiments with several remote users of the STEP I system. These include academic researchers at other universities and government agencies. The experience gained during this year will aid us in gaining understanding of the problems of using large, complex systems in a research mode over the ARPA Network.

4. ILLIAC IV LANGUAGE DEVELOPMENT FOR THE PHASE II SYSTEM

4.1 Summary

During the latter part of this period, a study began to address the need for a convenient linguistic and systemic means to specify and control timely flow of information between hierarchic memory levels in support of a non-core contained computation on ILLIAC IV. Incorporation of run time hardware allocation constraints into the data flow process is also a problem.

As an ideal solution, one would like to have a compiler which would accept the source program and the run-time storage allocations, and produce the appropriate set of ILLIAC IV, Memory Management Processor (MMP), PDP-10 and CCA datacomputer "programs" necessary to efficiently support, synchronize and perform the indicated computation. Work during the next six months will attempt to identify the framework and methodology necessary to support attainment of these goals.

5. ILLIAC IV INFORMATION RETRIEVAL AND STATISTICAL SYSTEM (IRSS)

5.1 Summary

An investigation was made and completed on information retrieval using ILLIAC IV. The conclusions reached were that the machine is not suited to the general problems of information retrieval and data management due to the awkward I/O structure, i.e., the lack of parallelism in I/O. However, files that can be linearized for serial searches are applicable to the ILLIAC since PE parallelism can be exploited. Serial searching is no longer a general problem of data management due to random access equipment and techniques. If serial search is necessary, it can be done on the IV; however, its use is probably limited.

In November, functional and detailed design of the IRSS began. Progress is slow as the System has dependencies on the datacomputer and the Ames Phase II System which are not completely defined.

The scope of the IRSS has been decided and includes the following:

(a) The IRSS will relate to information retrieval, not to information management.

(b) It will provide a user-language (non-procedural) and recognize data-item names.

(c) The IRSS will provide data manipulating routines (statistical) identifiable through the user-language, operable in the ILLIAC IV.

(d) The IRSS will be developed with the Ames Phase II system as its base.

(e) The datacomputer will be used.

(f) The IRSS will provide a means for researchers whose data reduction problems are large enough to warrant use of the ILLIAC IV to gain access to it.

(g) Data transposition routines will be available for users who need a specific format of data in PE Memory.

(h) The IRSS will be interactive but will not guarantee response in terms of completion.

With this emphasis, the next period will involve the development of the user-interface that is the non-procedural language. Based on the current state of the Ames I/O design, detailed design of the interface to the ILLIAC IV operating environment will be deferred. Design and implementation of the language, symbol tables, parser, and translation to data language will be investigated.

An initial version of a user-oriented interactive, file handling system called MONICA was completed during this reporting period. MONICA was developed to provide researchers easy access to a set of statistical subroutines. Emphasis was given to the user-interface and this experience will be used in developing the IRSS user-interface. A user's manual for MONICA will be produced in the next quarter.

Work was begun on defining user needs for an ILLIAC IV Statistical System and for reviewing existing systems. The ILLIAC Statistical System will be an integral part of the ILLIAC Information Retrieval System.

Dr. David Beckles, presently of the University of Newcastle-on-Tyne, England, will join the staff of the Center in August to take primary responsibility for the design and implementation of the ILLIAC Statistical System. In January of this year, discussions were held with a number of eminent users and designers of large statistical systems. The consensus of this series of meetings was that it would be unwise to implement a national resource like the ILLIAC System without continuous consultation with the user community. We intend, therefore, to set up from the user community a statistical advisory committee to provide comments and suggestions to the design group. Dr. John Sonquist, Professor of Sociology at the University of California at Santa Barbara has agreed to head the advisory committee.

6. ILLIAC IV IMAGE PROCESSING SYSTEM

6.1 Summary

At the request of NASA's Earth Observations Program, the Center is presently exploring the application of the ILLIAC IV hardware sys- ' m to the large-scale data storage and processing problems associated the automatic interpretation and management of high-altitude air- c. t and satellite earth resources imagery.

As background for this effort, the Center has surveyed existing methods of earch resources data collection by remote sensing, currently operational hardware and software systems for data processing, interpretation and information management, and meaningful applications of the technologies to specific problems of social concern. Preliminary investigations have shown the ILLIAC IV capable of efficiently processing, interpreting and managing large quantities of multi-spectral, digital imagery. The ARPA Network seems a practical means for interfacing the numerous, geographically-dispersed, potential users of such a system.

As a result of these initial determinations, the Center is preparing a proposal to NASA (and perhaps to other federal agencies) for the design and implementation of a prototype ILLIAC IV-based information processing system to support NASA's Earth Observations Program. The Laboratory for the Applications of Remote Sensing of Purdue University, supported by NASA, is assisting the Center in this effort and has agreed to lend methodological expertise to future efforts. NASA-Ames Research Center has also participated in preliminary explorations and has expressed substantial interest in such a proposal.

7. EDUCATIONAL ACTIVITIES

7.1 Documentation

(a) Volume 1 of "An Introductory Description of the ILLIAC IV System" was published on July 15, 1971. Two hundred copies were sent to Ames and three hundred copies were kept at the University of Illinois. Following is an abstract of the book:

Written specifically for an applications programmer, the book presents a tutorial description of the ILLIAC IV System. Volume 1 contains three chapters-Background, Hardware Structure and the Assembly Language, ASK, as well as a Hardware Glossary. Many illustrative problems are used to educate the beginner in the use of the ILLIAC IV System.

(b) A very short "Ten Page Description of the ILLIAC IV System" is now in preparation. It was synopsized from "ILLIAC IV Hardware Structure," presented at the Ninth Annual Allerton Conference on Circuit and System Theory in October 1971 and from "The ILLIAC IV System," written for the IEEE.

7.2 Teaching and Consulting

(a) CS 491, "Architecture, Applications and Languages for a Parallel Computer" was offered at the University of Illinois as a graduate course in the Computer Science Department. The course has now been changed to CS 397 "The ILLIAC IV Computer System" and is being taught this semester.

(b) Short (one-hour to one-day), informal seminars dealing with the ILLIAC IV System were given to University of Illinois staff and students. Some consulting concerning ILLIAC IV was done by telephone with people outside the University community.

7.3 Training

Two Affirmative Action programmer trainees are being trained in the arts and crafts of programming for a digital computer and in algorithmic problem solving.

8. ADMINISTRATION

8.1 Fiscal Status

Actual expenditures through 31 December 1971: $434,186. Estimated expenditures and obligations through 31 March 1972:

January	February	March
$81,300	$100,714	$106,800

Total estimated through 31 March 1972: $723,000.

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